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A SYSTEM FOR ORIENTING BALLOON PAYLOADS IN SPACE

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GODDARD SPACE FLIGHT CENTER
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By

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ABSTRACT

An inexpensive system for orienting balloon payloads to allow a detector to view a fixed position on the celestial sphere is described. The basic system is a sun seeker with programmed motion to correct for earth rotation and wind drift and to thereby provide relatively accurate orientation toward any desired direction on the celestial sphere. Two successful balloon flights have been flown utilizing this oriented platform, which can be used, with minor modifications, for a large number of applications.

Author

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INTRODUCTION

The purpose of this paper is to describe an orientation system developed at the Goddard Space Flight Center for orienting moderately heavy detector payloads to point at a fixed position on the celestial sphere. The objectives were to build an inexpensive and relatively simple system which would be reliable and sufficiently accurate to maintain orientation to within a one degree pointing cone, for detectors weighing up to about fifty pounds. The system to be described has been flown twice successfully in a nuclear emulsion investigation of point sources of gamma-rays. The results of the experiment are reported elsewhere.[1]

PRINCIPLE OF ORIENTATION

To provide orientation, a system must be able to sense two directions on the celestial sphere, if it is desired to point at any general third direction. The large flux of energy emanating from the sun in the visible wavelength region provides a source which can easily be sensed for one of the fixed points, however, a second source of this magnitude is not readily available. However, a second direction which can be sensed easily is that of the earth's gravitational field, but the earth vertical vector at the point of the experiment is not fixed on the celestial sphere, both because of the rotation of the earth and the drift of the balloon with the high altitude winds. However, since each of these movements can be well predicted, appropriate corrections can be programmed into the orientation to provide a second fixed reference point on the celestial sphere. These are the two sensing directions used for this orientation system.

[1] C. E. Fichtel and D. A. Kniffen, J. Geophys. Res., 70, 4227 (1965).

The problem of pointing toward a source on the celestial sphere while orienting toward the sun arises because the ballon drift and earth's rotation cause such a source to make an apparent rotation about the sun at a non-uniform rate. To determine this angle of rotation in a plane perpendicular to the earth-sun line, one may use the perpendicular projection of the north vector (Fig. 1), as a reference which is fixed in celestial space and the perpendicular projection of the vertical vector at the point of the experiment as a reference which is fixed in the rotating frame. The angle β differs by, at most, an additive constant from the necessary angle of correction. If we designate the projection of V as P_v and of N as P_n then

$$\beta = \arctan \frac{(P_v)_\perp}{(P_v)_{\parallel}}$$

where $(P_v)_\perp$ $\left[(P_v)_{\parallel}\right]$ is the component of P_v perpendicular [parallel] to P_n. Then

$$(P_v)_\perp = V \cos \theta_v \sin (\phi_v - \phi_s) ,$$

$$(P_v)_{\parallel} = V \sin \theta_v \cos \theta_s - V \cos \theta_v \cos (\phi_v - \phi_s) \sin \theta_s .$$

Hence

$$\beta = \arctan \left(\frac{\cos \theta_v \sin (\phi_v - \phi_s)}{\sin \theta_v \cos \theta_s - \cos \theta_v \cos (\phi_v - \phi_s) \sin \theta_s} \right), \tag{1}$$

where

θ_v = latitude of the location of the experiment,

ϕ_v = right ascension angle of the location of the experiment,

θ_s = declination angle of the sun,

ϕ_s = right ascension angle of the sun.

All of the variables remain essentially constant during a typical balloon flight, except for $(\phi_v - \phi_s)$ which varies due to the combination of earth rotation and balloon drift. The accuracy is therefore dependent on an accurate prediction of the high altitude winds. If sufficiently accurate wind data is not available it

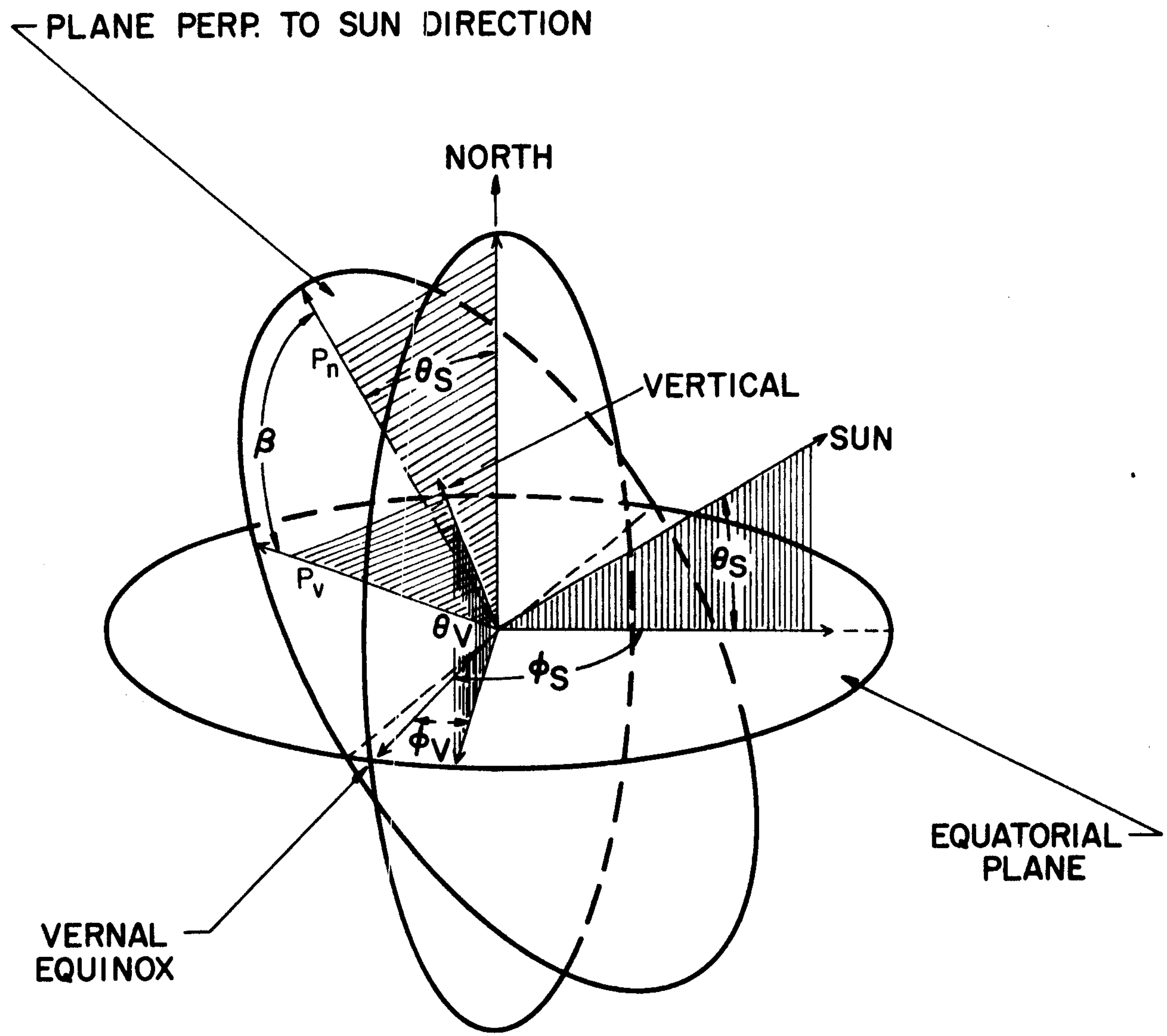

Figure 1 – A three dimensional diagram of the geometry involved in determining the motion required by the programmer.

might be necessary to launch a small trial balloon with tracking equipment to obtain this information. It might also be desirable to include latitude variations (θ_v) in the programmed motion, if a North-South wind component exists.

MECHANICAL AND ELECTRICAL CONFIGURATION

The basic flight unit as pictured in Fig. 2, consists of a framework supporting the experiment, sensing units, programmer, and power supply. Attached to the lower end of the frame is the inertia wheel and support equipment container. Scaling of the dimensions can be tailored to the individual experiment needs. For this experiment an inertial wheel diameter of forty-eight inches and an overall height of about sixty inches were used.

A block diagram showing the relationship of the principal mechanical and electrical components is included as Fig. 3. The azimuth drive motors are mounted at the top and bottom of the framework. The top motor is geared to a swivel through which the unit is attached to the balloon and the bottom motor is geared to the inertia wheel. The lower drive assembly also contains a system of slip rings to transfer information to the support equipment container for telemetry.

The primary correcting force for azmuthal orientation is provided by driving the inertia wheel in the direction opposite to the desired correction. Because of bearing friction and the rather low torsional rigidity of the suspension lines it was necessary to put an additional motor and gear system at the upper end of the unit. This motor is geared to turn the suspension swivel at the rate and in the opposite direction to which the frame would turn if suspended from a frictionless bearing. This device prevents twisting of the suspension lines and the resultant feedback of motion to the gondola.

The elevation orientation system consists of a counterbalanced cradle assembly on which is mounted the payload and elevation sensing units. This cradle is rotated by a reversible dc motor and is restricted by limit switches to a 90-degree travel from horizontal to vertical.

The sensing units for both the azmuth and elevation units are adaptations of units used by Shechet[2]. They consist of an interference shade located between two symetrically mounted photovoltaic cells, Hoffman type 220 C. The sunshade casts shadows on the cells partially obscuring their sensitive areas. The output

[2] M. L. Shechet, Rev. Sci. Instr. 31, 546, (1960).

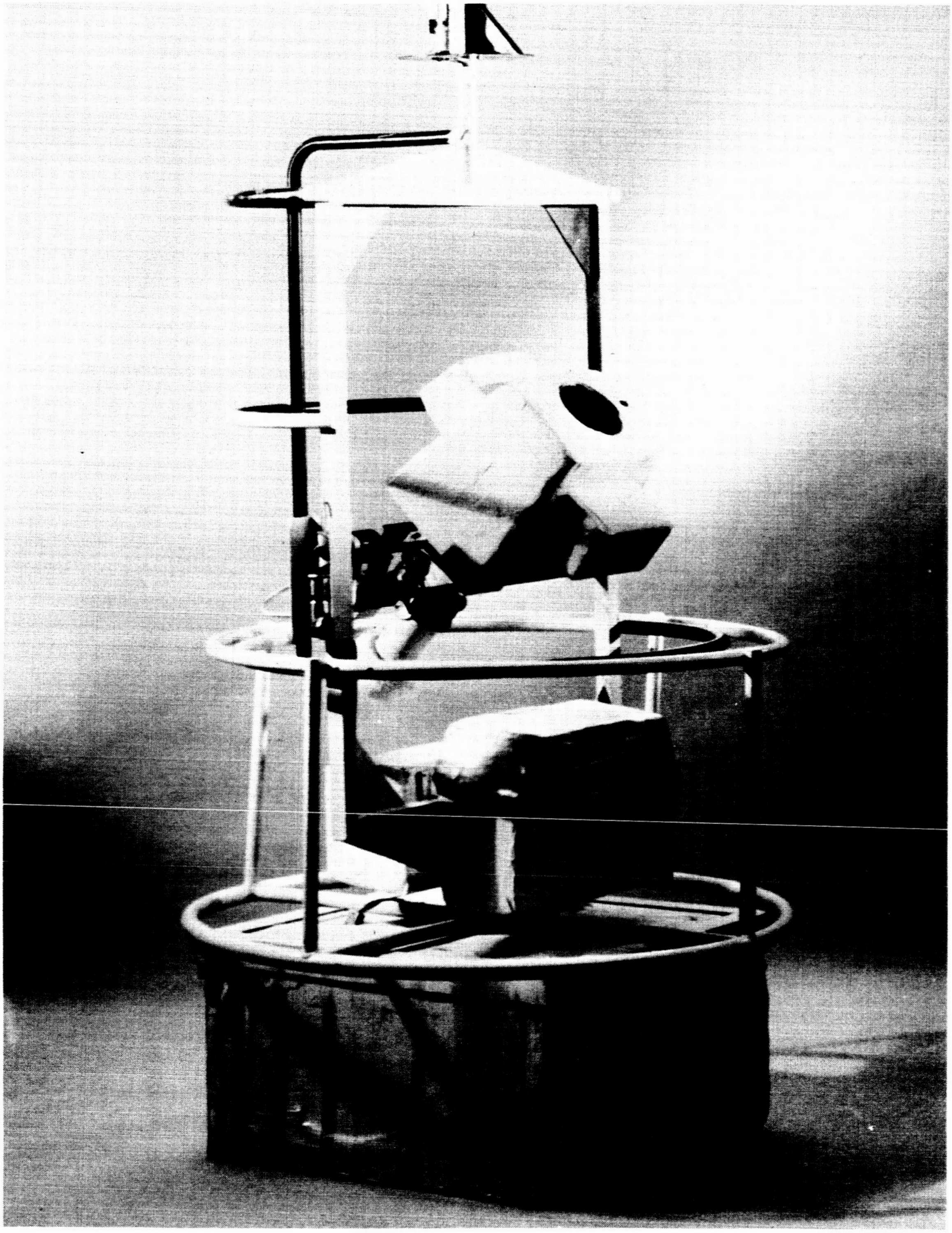

Figure 2 – A photograph of the assembled gondola prepared for flight.

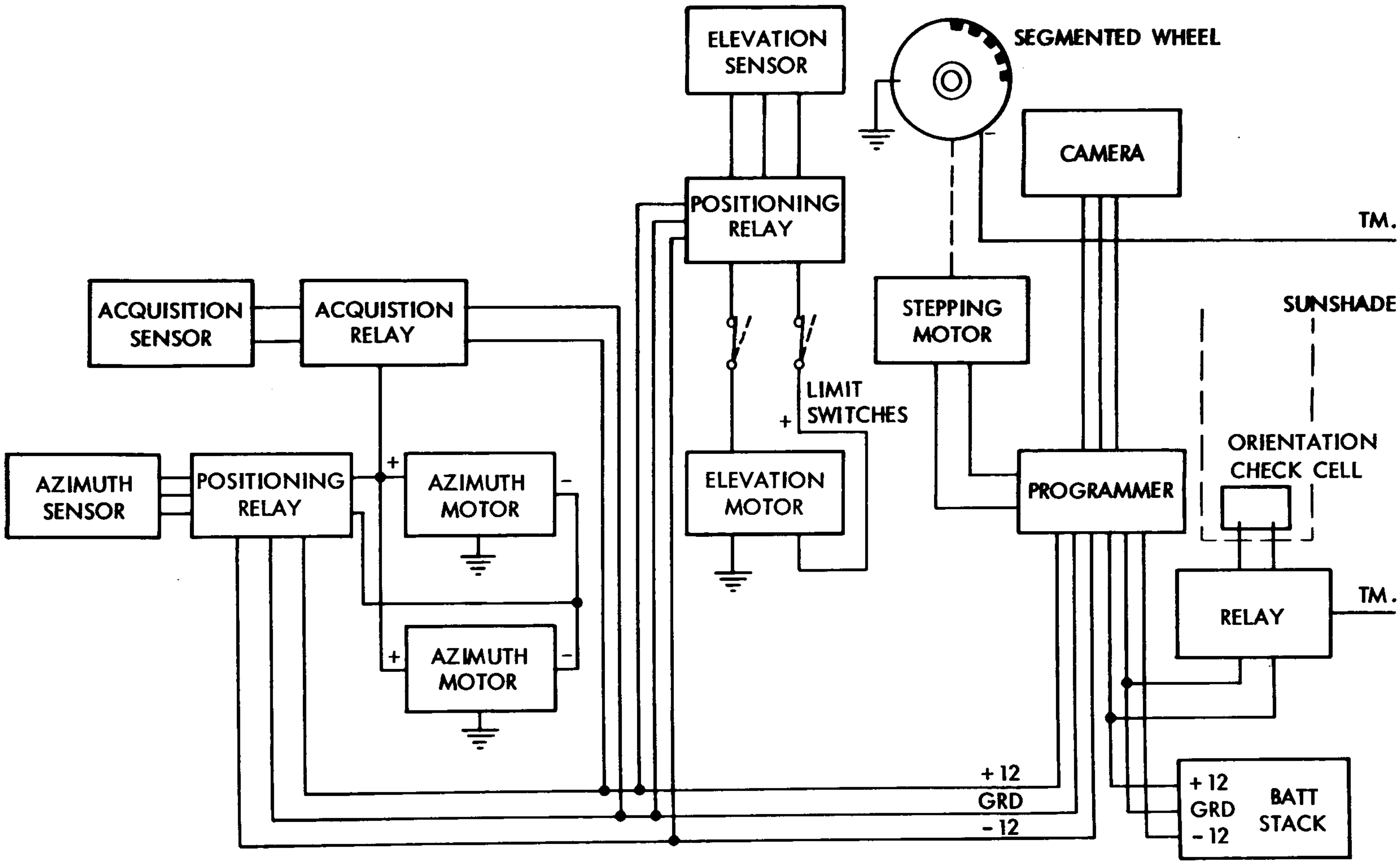

Figure 3 – A block diagram of the electrical system of the orientation platform.

of each of these cells is placed across one coil of a double coil sensitive relay, Barber Coleman Model 7875-100. The resultant effect is such that when pointing directly at the sun the relay is balanced, with neither contact closed; if, however, a pointing error is present one cell is shaded more than the other. The difference in current caused by the unequally lighted areas of the cells causes the relay to close one set of contacts sending a 12 volt dc input to the positioning motors.

To resolve the obvious 180-degree ambiguity in initial acquisition, a third cell is used in the azmuth detector system. This cell is placed 180 degrees away from the sensing cells and is connected to a separate sensitive relay. This system is adjusted in such a manner that if both sensing cells are completely shaded the acquisition cell will be lighted. This cell will actuate the relay which in turn applies a voltage to the positioning motors, and thereby moves the payload into the range of the normal sensing cells.

THIRD AXIS ORIENTATION

To provide orientation in celestial space, as outlined above, a programmed rotation of the experiment about the earth-sun line is necessary. This motion is provided in increments of 10 seconds of arc by a stepping motor which drives through a precision speed reducer. The stepping drive assembly rotates a shaft on which is mounted the experiment and orientation check camera.

Variable timed pulses to duplicate the rate of change of β as given by Eq. (1) are generated by a punched tape programmer. The unit used is a modified Beattie Coleman Model MLPR-13. In addition to providing the rotational rate pulses, the programmer also handles the functions of triggering the orientation check camera, to be discussed in the next section, as well as turning on the orientation system upon reaching ceiling altitude and shutting the unit off at the termination of a flight.

INFLIGHT SYSTEM CHECKS

To provide data on the performance of the system during flight, three independent check systems were provided. For a real time sun pointing check, a photovoltaic cell was placed in the bottom of a tube which was aligned with the pointing axis of the sun seekers. The geometry of this arrangement was such that the output of the cell would actuate a relay when the unit was aligned to the sun to within approximately five degrees. The actuation of this relay provided a signal, through slip rings at the base of the unit, to the telemetry equipment mounted in the support equipment container.

To verify proper functioning of the third axis orientation system, a separate channel of telemetry was provided. The signal for this function was generated by a segmented wheel which rotated with the experiment. A wiper system was so arranged as to cause the signal to change every three degrees of rotation in β.

The primary check of orientation is provided by photographic means. A motor driven 35 mm camera with a 500 mm lens was mounted on the experiment platform. The camera has a capacity of 250 exposures and these were spaced by the programmer at 2-minute intervals during the time at altitude. A special type 5-0 spectroscopic film, produced by Kodak, was used to provide maximum contrast and resolution of the sun's image. The lens opening was fixed at f/5 and the shutter speed was set at 1/30 second.

The field of view of the camera was three degrees with the sun's image subtending approximately one-half degree. A plot of the pictures taken during a flight is shown in Fig. 4. Each point on the plot represents the average of ten exposures. As this figure indicates, the inflight accuracy of the system is about $\pm 1/2$ degree.

COST AND WEIGHT

The system described in this paper was built at a cost of about $8,000.00. A large percentage of this cost was expended in the programmer and camera systems. The modification of existing equipment, use of a less expensive camera, and construction of a less complex programmer could cut this cost by at least a factor of two.

The total weight of this system was about one hundred and forty pounds, of which the oriented portion comprised approximately forty pounds. The geometry of the frame and the arrangement of the experiment platform could easily be designed to fit the particular experiment configuration required.

A breakdown of the commercial parts utilized in the construction of this unit is included as Appendix A.

ACKNOWLEDGMENT

The constant interest and advice of Dr. C. E. Fichtel, co-experimenter of the gamma-ray experiment, during the design phase of the orientation system are gratefully acknowledged.

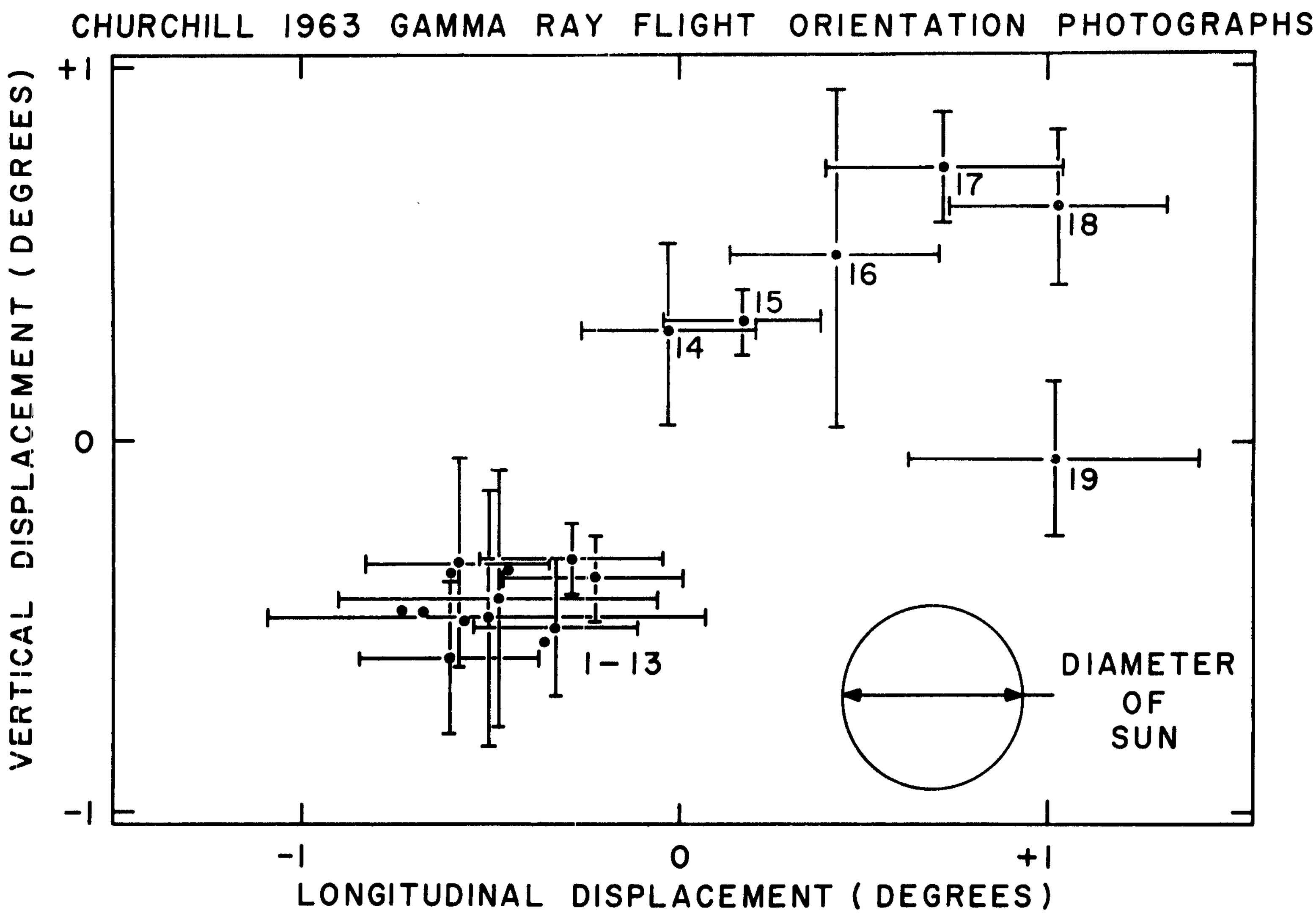

Figure 4 – A data plot of pictures of the sun taken with the orientation check camera during flight. Each data point represents an average ten exposures.

Appendix A

Commercial Parts Used

A. Orientation System

1. Hoffman Photo Cells, Type 220 C.
2. Barber Coleman Micropositioner Relay, Model 7875-100.
3. Barber Coleman 12 V, dc Permanent Magnet Motor, Part No. BYLM 72810-13.
4. Pic Gears, slip clutches, etc.

B. Stepping System

1. Ledex Syncramental Motor Series 3, Part No. D-9191-001.
2. Pic Precision Speed Reducer 200:1, Catalog No. U4-13.
3. Pic Spur and Antibacklash gears.

C. Programming System

1. Beattie Coleman Programmer, Model MLPR-13.

   (Modified to 24 V dc operation by substitution of a Glove 3600 RPM governed dc motor for the existing 110 V ac motor.)

2. Beattie Colemen Tape Punch, Model PU-35.

   (To place orientation and function information onto 35 mm mylar tape).

3. Reversing and Relaying Circuit by Litton Industries Special built using following components:

   1) Potter and Brumfield SC-11D Relays
   2) Sigma 32RJ-200G-Sil Relays
   3) Sigma 32RJP-3100G-Sil Relays
   4) Ledex 4 position 24 V dc Stepping Switch
   5) Misc Capacitors and resistors

D. Camera System

1. Nikon, single lens reflex 35 mm Camera body, model F., Prod. No. CA 1505.
2. Nikon, Elec. Motor Drive /w 250 exposure film capacity, Model F250, Prod. No. EM 11.

D. Camera System (Cont'd.)

3. Nikkor 500 mm f/5 Reflex lens, Prod. No. LN-193.

E. General Items

1. Batteries Eveready Alkaline Primary Batteries 6 V, No. 520.
2. Pressure Switch, Gorne - Field Adjustable, Type GB-300-NA 65.